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ABSTRACT

An understanding of the stages involved in children's development of sensory motor integration would aid in the creation of instructional strategies in physical education. These strategies would optimize both the child's physical coordination and creative development by increasing the correlation between the demands of a learning environment and the capacities of the child's nervous system. Aspects of the development of sensory motor integration are discussed as they apply to two areas of motor control: eye-hand coordination and balance control. Behavioral changes in each area that occur from the moment the child is born to the point at which the behavior matures are discussed, as are developmental changes within the nervous system which may underlie the changing behavioral patterns. Practical applications of these studies for sequencing the teaching of motor skills in young children are suggested. (JM)

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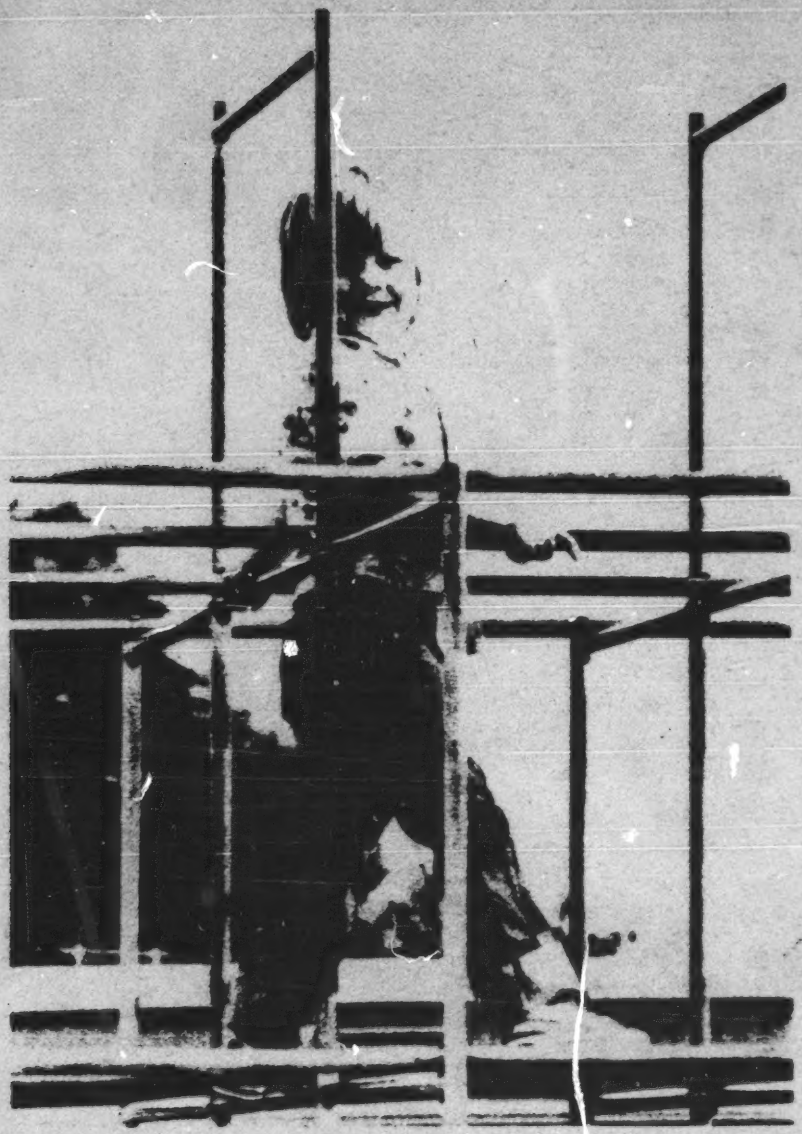

CHILDREN'S CHANGING CAPACITY TO PROCESS INFORMATION

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This paper is based upon the concept that an understanding of the stages involved in children's development of sensory motor integration would aid in the creation of instructional strategies in physical education. These strategies would optimise both the child's physical coordination and creative development by increasing the correlation between the demands of a learning environment and the capacities of the child's nervous system. Aspects of the development of sensory motor integration will be discussed as they apply to two areas of motor control: eye-hand coordination and balance control. In each area I will mention first the behavioral changes which occur from the moment the child is born to the point at which the behavior matures. Then I will discuss the developmental changes within the nervous system which may underlie the changing behavioral patterns. Finally some practical applications of these studies for sequencing the teaching of motor skills in young children will be suggested.

Eye-Hand Coordination

A question which has intrigued researchers interested in motor control for many years concerns whether the integration of these sensory and motor systems underlying visually guided reaching are genetically predetermined, or whether experience is required to "map" the visual space of the child onto the motor systems controlling movement. The first hypothesis implies that once the sensory motor pathways for visually guided reaching have matured, the child will be able to reach accurately for an object with little or no prior experience. The second hypothesis predicts the requirement of a learning period during which the child formulates through trial and error, a visual map which overlays a manipulative map. As with most cases of alternative hypotheses which support two extremes of a continuum, there is no clear evidence supporting either extreme viewpoint. When the conflicting data from many studies are compared, a pattern begins to emerge which supports elements of both views contributing to the development of eye-hand coordination.

Piaget's (Piaget, 1952) observations on the development of motor control led him to believe that maturation of the nervous system is a basic requirement for the appearance of a behavior, and that experience is responsible for coordination of the senses: if a behavior is given no environmental stimuli to assimilate it will die away. He believed that through repeatedly and simultaneously looking at and touching an object of a certain shape, the visual and tactile sensory impressions become associated.

To further support this hypothesis, White and his colleagues (White, Castle and Held, 1964) noted that infants demonstrated both visual and manual actions in the first weeks of post natal development, but that these actions were unrelated. This has led many developmental psychologists to support the theory that intersensory development (coordination of sensory inputs) takes off from birth, at which point vision and touch are not in any way integrated. Bushnell (1982) summarizes this point of view in saying "at birth, visual and tactile space exist, but they are not related to one another".

However, Bower and his associates (Bower, Broughton, and Moore, 1970; Bower, 1972; and Bower, 1974) presented evidence approximately ten years ago which they believed supported the concept of a clear coordination between eye and hand in the newborn child. They stated that when a child between 7 and 14 days, who was born without anesthesia, is posturally supported in an infant seat in order to allow more freedom of arm movement, he shows arm movements clearly directed toward an object placed in his visual field. In their 1970 paper they reported that a significant portion of the infants' reaches were to within 5 to 10 degrees of the object. Developmental psychologists and neurologists were puzzled by these reports be-

cause coordination between visual and manipulative abilities in children was thought to be acquired gradually during the first few months of post-natal development.

Bower's studies have been criticized by researchers who have not been able to obtain the same percentage of infant reaching or the same degree of accuracy (Dodwell, et. al., 1976; Ruff and Halton, 1978). Subsequent studies by DiFranco and his colleagues (1978) found that some of the components of reaching could be observed, but in a less successful and less coordinated form. Ruff and Halton (1978) found that the number of close or clear contacts with the objects was small enough to be considered fortuitous. However, their use of a pillow instead of an infant seat for support of the infant may have lead to an inability of the infant to freely move his/her arm.

A more recent study by Von Hofsten (1982), uses a slightly different experimental paradigm to support the contention that a coordination between eye and hand exist in the newborn (5-9 days of age). He used a slowly moving object to attract the child's attention and measured the number and distribution of arm-hand movements when the object was present or absent. He showed that a higher portion of movements which the newborn performed while fixated on the object were extended forward, than in any other direction. It was also shown that those movements were aimed closer at the object than were other movements.

He concluded that the visual-motor space within which the newborn reaching movement is performed has a well-defined directional structure and that the system not only works from eye to hand but also from hand to eye, since several instances were noticed when the infant accidentally touched the object and immediately turned his eyes toward it. It was also evident that the catching, grasping, and manipulative functions were not fully developed in the newborn, since they rarely grasped the objects. The actions considered preparatory to grasping (such as slowing down and opening the hand during the movement) occurred in only about half of the fixated reaches.

Von Hofsten concluded that the function of newborn reaching systems seems to be more attentional (pointing) than manipulative. He implied that the coordination of the exploratory systems of the child are preadapted and that they constitute an appropriate foundation for the subsequent development of eye-hand coordination.

McDonnell (1979) gave further evidence that infant arm movements are oriented to visual targets by looking at the distribution of an infant's arm movements over time, comparing the number and direction of responses when a target was in an initial position (considered background activity), to those when it was moved to a new position. The question was whether the infant's arm movements indicate that the infant detects the change in position. The frequency distribution of index finger position in the two situations supported the hypothesis that limb movements are oriented to visual targets in infants of three weeks of age.

When one compares the above results with experiments performed on both primates and cats, one finds results which begin to pull together the two sides of the controversy concern the role of genetic predetermination and experience. In 1963 Held and Hein showed that cats initially reared in the dark failed to perform visually guided behaviors such as paw placing or blinking when an object approached them rapidly. However, if these animals were subsequently permitted to spend as little as 7-10 hours within a normally illuminated environment, normal visual guided behaviors were acquired. Similar experiments performed on monkeys (Bauer and Held, 1975), showed that visually guided reaching may be limited to one forelimb if the other has not been viewed during development. However, within one hour in normal conditions they could reach out and grasp objects.

On initial reading, one might take these results as strong evidence to support the hypothesis that experience is necessary for children to produce normal visually guided movements in space. At one level this is true, since experimental animals cannot make normal visually guided movements when they are reared as described above. But with further contemplation, what seems more important is the speed with which their systems gain full control over visually guided movements when presented with normal environmental conditions.

If these data are taken in support of the concept of a neurophysiological tabula rasa on which visual and manipulative space are mapped during early experience, it implies that this learning does not consist of long term trial and error behavior, but is rather akin to the imprinting observed early in the development of many animals.

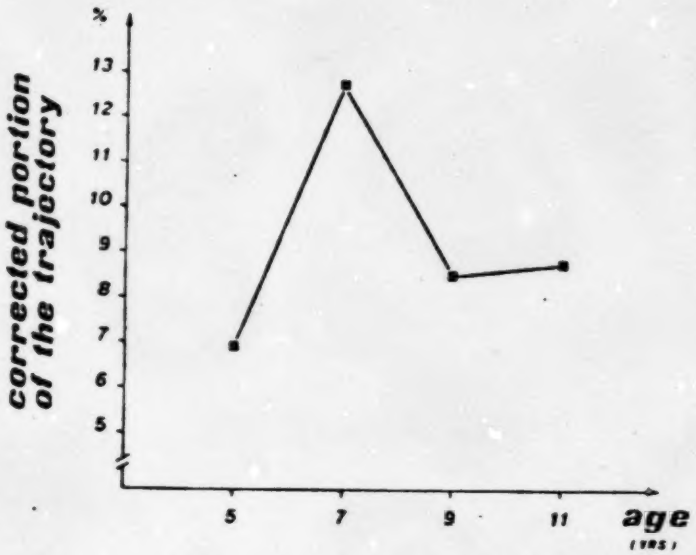
Development After Birth

Most studies concur that true visually guided reaching, or the individual's ability to modify activity already in progress on the basis of current visual information, appears at approximately four to five months of age (Bower, 1974; Bruner, 1973; White, Castle and Held, 1964; and McDonnell, 1979). Lasky (1977) and McDonnell (1975) found that failure to see the hand in the visual field began consistently to disrupt the reaching and retrieval behavior of children only at five and one-half months. McDonnell used prisms to create a true visual guidance condition, while Lasky used mirrors to create a condition of true ballistic reaching (infants attempted to reach for a virtual image of a toy with the site of the arms blocked by a mirror).

McDonnell (1979) found that the development of visual guidance as a characteristic mode of reaching, peaks at about 7 months of age. However, it is gradually replaced by a ballistic style during the second half of the first year of life. He concludes that this return to a ballistic style is due to the relative slowness of visually guided reaching and its subsequent inefficiency in most common reaching tasks. He emphasized that eye-hand coordination is relatively plastic in this period of development as demonstrated by right-left hand laterality shifts to suit the conditions of the task, and by the ease with which the infants adjust to wearing prisms causing intersensory conflict.

While visually guided reaching behaviors have been studied extensively in the newborn through one year old, studies of older children are apparently lacking up to the age of four. Studies which have been performed on children between the ages of 4 and 11 (Hay, 1978; 1979) show an intriguing repetition of the developmental sequence found in the first year of life. Hay compared the accuracy of both active and passive reaching movements toward a target under open-loop conditions (i.e., they could not see their limbs) in children aged 4 to 11. She showed that accuracy was correlated with age such that the younger children (4, 5, and 6) performed very accurate movements. In the 7 year olds, accuracy suddenly decreased, after which it progressively increased until the age of 11 when levels close to those of adults were obtained.

In a second study, she correlated this decrease in accuracy with an increased reliance on visual guidance in the 7 year old age group. She showed that when the children were required to wear displacing prism lenses which measured the visually guided part of their trajectory, the 5 year olds showed predominantly a ballistic movement, the 7 year olds a visual guidance system, while the harmonious integration of the two systems was acquired at 9 to 11 years of age (see figure below).



Mean levels of trajectory correction as a function of age.

She proposed that feedback is probably relied upon heavily during motor program building or modification. If this theory is correct, it would suggest that there are critical periods during development in which manipulative motor programs are modified. The cause of these modifications could involve either nervous system developmental changes, or perhaps changes in the biomechanical characteristics of the body which force changes in the nervous system programming for optimal function.

A recent article by Kugler, Kelso and Turvey (1982) focused on the question of the factors underlying the transition between stages during motor development. They were concerned with defining the informational base (motor program) within the nervous system which is used to constrain systematically the body's degrees of freedom (i.e., accurately control movement) and how the informational base is coordinated with changes in the body's dimensions during growth period. They cited the evidence in motor development of step-wise or stage-like changes in movement organization (Roberton, 1978; 1982) which occur as a consequence of developmental age. They noted that for certain motor skills such as the overhand throw (Roberton, 1982), a relatively short period of time is spent in transition between stages while the plateaus of the stages are maintained much longer.

They hypothesized, based on thermodynamic and engineering principles, that for certain size changes in the body's dimensions, the organization of the nervous system's information base will be able to function effectively while remaining relatively invariant, while when certain critical dimensional changes are reached, the previously stable organization may break down and be replaced by a new organization. They emphasized that the important feature of this interpretation of a developmental sequencing of events is that a continuous change in a variable such as body size may bring about a sudden qualitative change in the motor program needed to control it.

Clearly, both nervous system developmental changes and biomechanical changes in body configuration will contribute to the behavioral changes seen as a child grows. It would be very interesting to attempt to define clearly the transition periods associated with these behavioral

changes in order to determine if they are correlated with unstable points in the biomechanical characteristics of the child's system, or if they are more closely associated with the maturation of a sub-component of the nervous system.

Even the young infant is capable of adapting muscle responses to changing task conditions if environmental conditions are large enough. McDonnell and Abraham (1979) have studied adaptation to visual prisms in infants 5 to 9 months. They found clear behavioral after-effects following brief prism exposure. This implied that infants easily adjust to intersensory conflict. They remarked, as do Kugler, et. al. (1982), that this plasticity is necessary, especially during the first year of life due to the remarkable growth rate of the body, including the head and arms.

Nervous System Changes Associated with the Development of Eye-Hand Coordination

In order to more easily interpret the behavioral data on the development of eye-hand coordination in infants, the following section presents a brief description of the early structure and post-natal growth of the nervous system. The visual system consists of two anatomically separate sub-systems which develop at slightly different rates in the infant's pre-natal and early post-natal life. The first system, often referred to in humans as the "primary" visual system is involved basically in the perception of pattern, and consists of neuronal pathways mainly from the central area of the retina, through the lateral geniculate nucleus, terminating in the striate area 17 of the occipital lobes of the cerebral cortex.

The more primitive second visual system has been hypothesized to be involved in the directing of the gaze to a relevant object in the peripheral visual field, and consists of neural pathways from the peripheral retina to the superior colliculus in the midbrain. Though research evidence is not available on human infants, research on other mammalian species has shown that the second collicular system can, by itself (without any cortical mediation) turn the eyes toward a relevant object (Humphrey, 1970; Smith and Warkentin, 1939).

Patterns of nervous system pre- and post-natal growth show that the more peripheral components of the visual system generally begin to mature at an earlier age than central components (Bronson, 1974), as judged by myelination studies. The superior colliculus and lateral geniculate nucleus show some myelination even before birth and complete the myelination process within the first months of infancy, whereas much of the cerebral cortex does not begin myelination until after birth, and myelination continues throughout the first ten years of life (McGraw, 1945; Yakovlev and LeCours, 1967; Bronson, 1974).

Though all areas of the cerebral cortex are not well developed at birth (Conel, 1947), at three months of age there are many signs that the cerebral cortex has begun to develop rapidly. This nervous system growth pattern corresponds nicely with the behavior of infants from birth through three months, in which one first sees, according to Von Hofsten (1982), first a primarily attentional eye-hand coordination which does not involve grasping, and subsequently, at about three to five months of age (McDonnell, 1979; Bushnell, 1982) a clear development of intentional motor control and of eye-hand coordination involving reaching and grasping. It is also of interest that the cerebral cortex continues to show maturational changes through the first decade of life, since it is only at 9 to 11 that eye-hand coordination stabilizes in an adult pattern (Hay, 1978; 1979).

The Development of Posture Control

Similar questions to those discussed above for eye-hand coordination can be expressed for the development of postural stabilization in infancy, i.e., to what degree is it triggered by and dependent upon visual input? In this instance,

relatively undisputed research evidence exists for the control of "postural" systems by visual input in the newborn. The first response to appear in infants which possibly may be associated with a postural system is classified as the response to "looming". Looming has been defined by Butterworth (1982) as accelerated optical expansion of a determined portion of the visual field. In other words, looming refers to the expanding image of an object as it approaches. It has previously been shown that many different species show an innate avoidance of looming objects (Schiff, Caviness, and Gibson, 1962). It is hypothesized that this behavior is due to this pattern of visual information which specifies imminent collision with the approaching object.

Responses to looming have been found in newborns (6 to 9 days) and infants of two weeks of age (Bower, 1974; Bower, Broughton and Moore, 1970). The behavior response seen is one of postural adjustments of the head involving withdrawal, and a raising of the arms. This occurs whether the stimulus is a real object or its optical equivalent. It is interesting to note that the response only occurs when an optical expansion pattern is on a collision course with the infant. If the pattern is asymmetrical, the child tracks it, but gives no other response (Ball and Tronick, 1971).

Cicchetti and Stroufe (1978) have further shown that these same patterns elicit avoidance patterns in Down's Syndrome infants of two months of age. According to Butterworth (1982), this could be considered as support for the maturationist hypothesis, since Down's Syndrome children are known to show delays in the development of neuromuscular control. Though this may not be conclusive evidence in support of a maturation-oriented hypothesis of perceptual-motor control, it at least suggests that infants respond posturally to structured properties of the visual environment before they begin to stand and walk and before they experience extensive tactile or kinesthetic input.

Studies on the further development of the postural control system in infants who are able to sit and stand independently show the emergence of a visual control system concerned with the maintenance of postural stability. Butterworth and Hicks (1977) have asked questions, similar to those seen in the section above on eye-hand coordination, concerning whether vision acquires its "proprioceptive" function in postural control as a consequence of experience or as a result of nervous system maturational processes. They put infants on a stable floor inside a room whose walls and ceiling moved forward or backward as a unit. This created visual feedback consistent with that which would be experienced during body sway. It had previously been shown (Lee and Aronson, 1974) that infants capable of standing independently "compensated" for this non-existent sway and fell in the opposite direction to the movement. Butterworth and Hicks (1977) showed that infants who could sit but not stand gave at least as great a response to this inappropriate visual feedback as those who could stand without support. They thus concluded that vision does not acquire its proprioceptive function in posture control as a result of experience obtained during practice in upright stance.

Butterworth and Cicchetti (1978) have compared Down's Syndrome and normal infants on these same tasks. They have shown that Down's Syndrome children who had recently learned to stand up unsupported were somewhat more responsive to movement of the visual environment than normal infants. In the standing posture the intensity of the response declined with experience for both Down's Syndrome and normal infants. Postural stability progressively became relatively independent of the movement of the visual environment. The infants were very unstable in the first three months after learning to stand and gradually stabilized during the subsequent year.

Butterworth (1982) mentions that it is interesting to note that adults can be made to rely completely on information

from the visual environment when in an unfamiliar or unstable posture such as balancing on a narrow beam (Lee and Lishman, 1975). He postulates that early in the development of posture control skills, balance depends strikingly on the congruence between visual, vestibular and somatosensory inputs, but with experience this control gradually shifts toward a dominance by the somatosensory and vestibular systems.

Butterworth (1982) believes that infant responses to looming objects and to movements of the whole visual surround are separately controlled, since optical flow patterns on the retinal periphery are required to induce the illusion of self-movement in adults, while the response to looming requires an expanding flow pattern in focal vision.

Forssberg and Nashner (1982) and Shumway-Cook and Woollacott (1983) have further explored the development of postural control mechanisms in children from one and one-half to ten years of age, using a movable platform to perturb the balance of the child while measuring his muscular responses with surface electromyograms (EMG's) (See Figure 2). We have found clear differences between children and adults when analyzing their postural response to support surface movements. These differences can be divided into three categories: 1) the temporal coordination of the responses of proximal and distal muscles within a synergic group, 2) the amplitude correlations of distal and proximal muscles within a synergy, and 3) the adaptation of postural response amplitudes to changing task conditions.

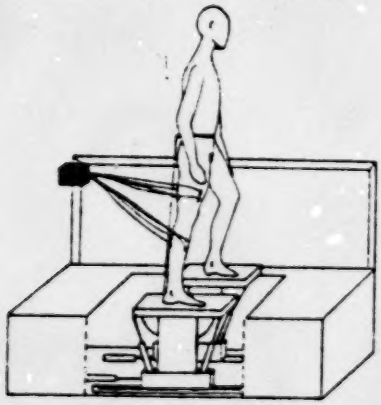
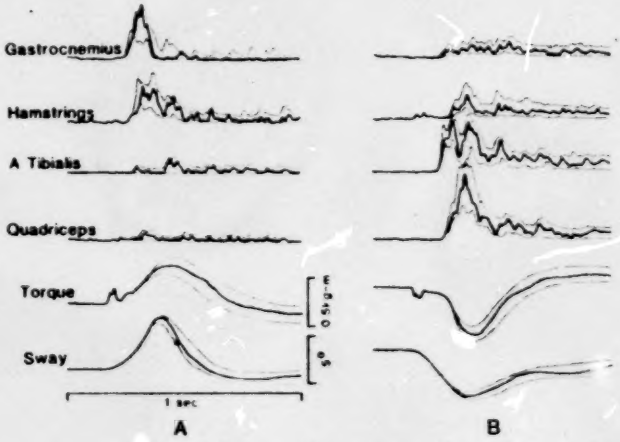


Figure 2

When the support surface on which an adult is standing is translated forward, one sees backward body sway and resultant muscle responses in the tibialis anterior (TA) muscle, followed shortly after onset by a response in the quadriceps (Q) muscles. In occasional adults, these initial muscle responses are followed by secondary responses in the antagonist muscles, gastrocnemius (G) and hamstrings (H). With subsequent trials the secondary responses drop out. The muscle responses serve to bring the center of gravity back to stability within the normal base of support. If the subject is caused to sway forward, muscle responses are elicited in a similar manner in the antagonist muscles. These muscle responses have been termed sway synergies, because the muscles contract in a fairly fixed temporal and amplitude relationship: the distal muscle is activated at approximately 100 milliseconds after a sway perturbation and is followed by proximal muscle activation 10 milliseconds later (see Figure 3 from Forssberg and Nashner, 1982).



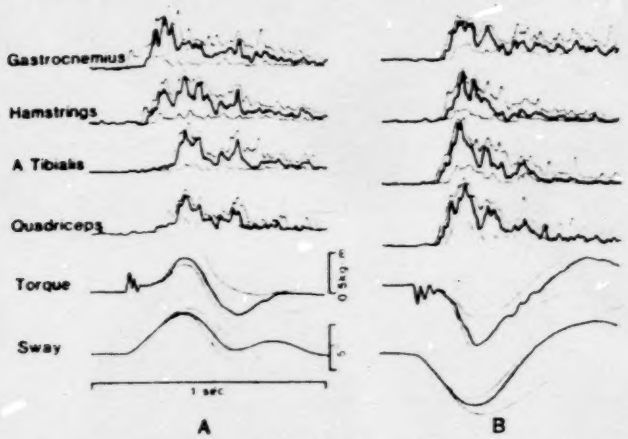
Five-trial ensemble averages (*heavy lines*) and upper and lower bounds (*fine lines*) of the EMG, torque, and sway responses

Figure 3

Proximal and distal muscles consistently contract in a fixed ratio to one another, though there is a variation in the amplitude of the muscle responses of the synergy as a whole from trial to trial. This can be seen in a very high intermuscular amplitude correlation ($r=.85$) within the adult synergy. Thus

adult postural muscle synergies have the following characteristics: 1) mean onset latencies of 100 milliseconds in the distal muscles, 2) directionally specific activation of muscles, beginning with the distal muscles, closest to the base of support, and spreading proximally, and 3) fixed temporal and amplitude (force) relationships between synergic muscles.

When comparing the responses of children from one and one-half to ten years of age to adults, the following characteristics were seen. Responses to platform translations for all children tested, including the youngest, were directionally specific and appropriately sequenced with distal muscles activated first. For example, for perturbations causing backward sway, TA was always activated first, followed by Q. However, in the majority of trials, children aged one and one-half to five showed additional activation of the antagonist muscles in both the distal and proximal muscle groups, in varying sequences. The synergies thus do not yet have the final refinement of the adult form (see Figure 4 from Nashner and Forssberg, 1982).)



Five-trial ensemble averages (*heavy lines*) and upper and lower bounds (*fine lines*) of the EMG, torque, and sway responses of a 2-year-old to forward perturbations (*A*) and backward perturbations (*B*).

Figure 4

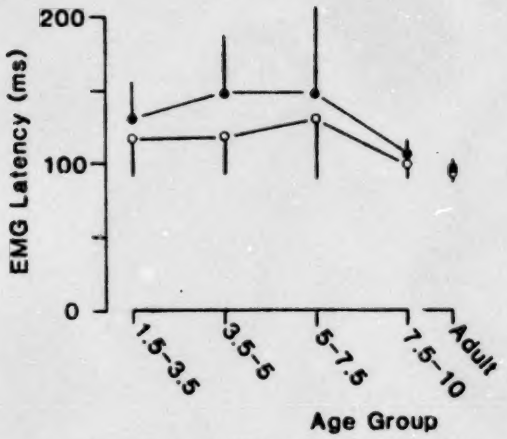
The activation of antagonist muscles could be a part of a trial and error process as a child learns to construct efficient adult-like synergies, or it could be an appropriate response to increased instability. It has been shown by Forssberg and Nashner (1982) and Shumway-Cook and Woollacott (1983) that in some postural perturbations the initial muscle responses result in over compensation for sway. Hence, antagonist muscle activity is needed to minimize postural oscillation (see Figure 5).

However, one cannot assume that antagonist activation represents an appropriate response to instability rather than a true structural difference between adults and children, since there are many trials where initial sway is minimal and all four muscles are activated.

One may conclude that the child possesses the correct adult synergy as early as one and one-half years of age (the age of the youngest child studied) yet lacks the necessary refinement of the synergy for accurate body sway correction.

Additional evidence which supports this conclusion is the finding of increased variability in response latency and amplitude in children aged one and one-half to five when compared to adults (see Figures 6 from Forsseber and Nashner, 1982, and 7) and increased temporal delays in the recruitment of proximal muscles within a synergy. In adults proximal muscles are activated at a mean of 18 7 milliseconds after distal muscles. However, in children aged one and one-half to six observed delays were 36 18 milliseconds for perturbations causing forward sway and 58 miliseconds for backward sway. Correlations of amplitudes of proximal and distal muscle responses within a synergy were low in children of this age group (= .45), when compared to adults (= .85) indicating less refinement of synergic organization.

Both absolute latency and variability of muscle response latencies show an interesting trend with increased age in children. Though Forssberg and Nashner (1982) did not comment specifically on this trend their data show a progressive increase in both absolute latency and



Average (±SD) EMG latencies of responses to forward AP sway perturbations (gastrocnemius, ●) and to backward sway perturbations (tibialis anterior, ○). Adult data were derived from Nashner, 1977.

Figure 6

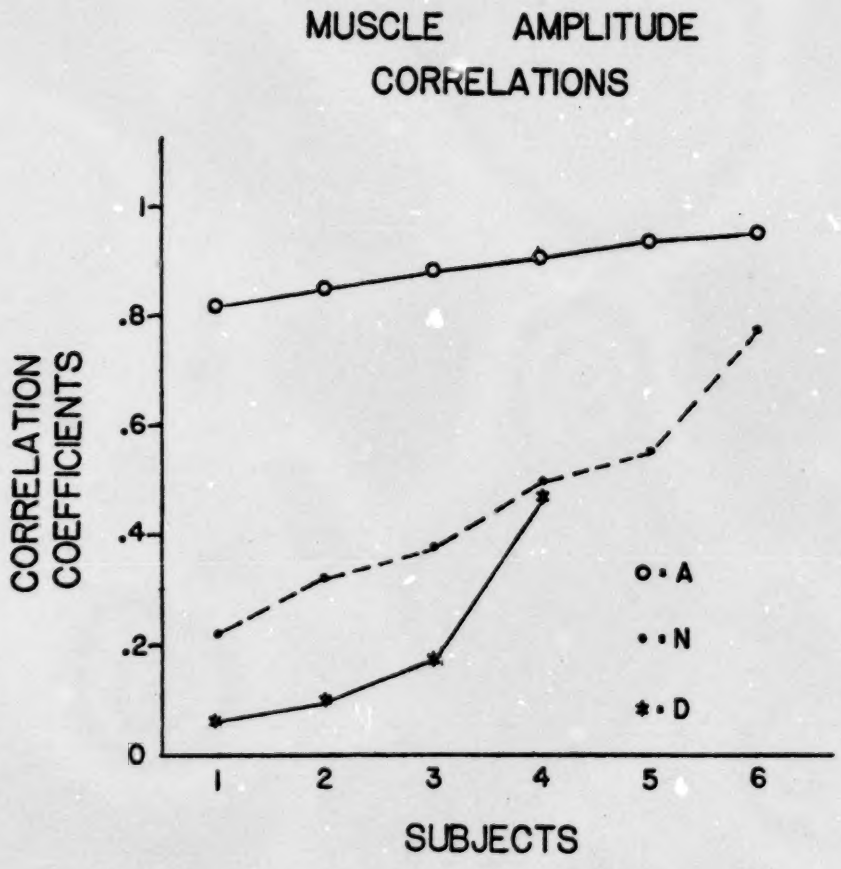


Figure 7

Distal-Proximal Muscle Amplitude Correlation. Correlation between gastrocnemius and hamstrings amplitudes over a series of ten trials is high in adults, indicating muscles are consistently firing in fixed proportion to one another. Correlation is less in normal children and low in Down's Syndrome children, suggesting automatic postural response synergies are not clearly established in Down's Syndrome children.

variability of muscle responses with age in the three youngest age groups they tested (1.5-3.5, 3.5-5, 5-7.5: see Figure 6). The absolute latency and variability abruptly decreased in their 7.5-10 year old age group, showing adult-like latencies and variability.

This trend is reminiscent of that seen by Hay (1978, 1979) in her children aged 4-11 during open-loop eye-hand pointing tasks. Though EMG's were not measured in the Hay study, error was shown to increase significantly in 6 and 7 year olds, when compared to 4 and 5 year olds. Further experiments by Hay demonstrated that the decreased accuracy was due to a change in eye-hand coordination mechanisms from visually pre-programed movements to a continuous guidance system at age 7. This was followed by an appropriate integration of the two systems by ages 9 to 11.

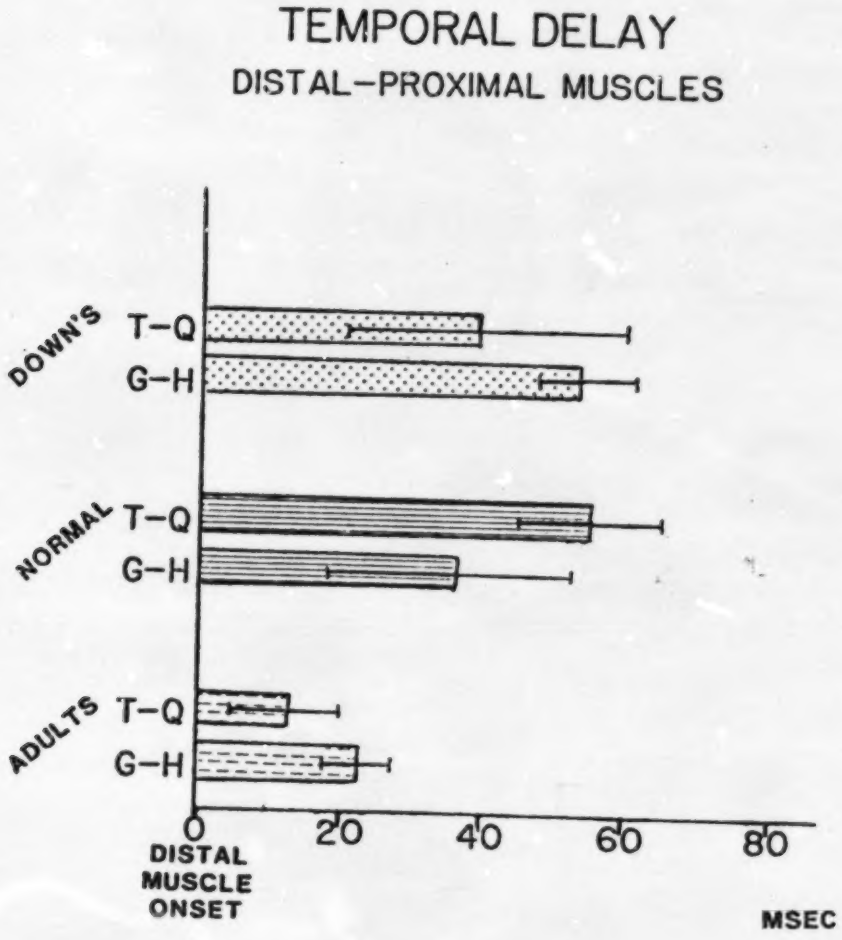
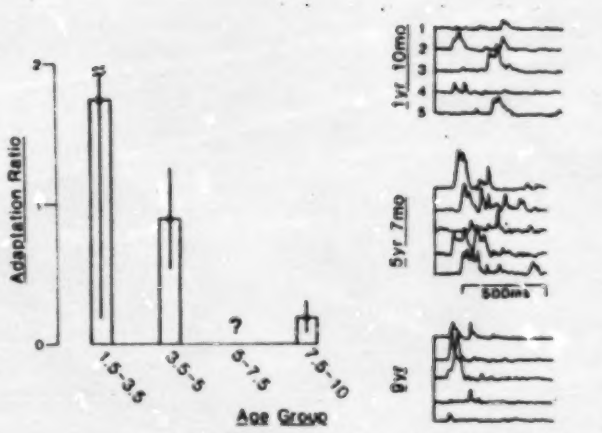


Figure 9

_____ Distal-Proximal Muscle Temporal Delay. Data from adults, normal children and Down's Syndrome children shows the temporal delay in onset between distal muscles and proximal muscles in plus and minus sway conditions. Normal and Down's Syndrome children show significantly longer delays in comparison to adults.

Perhaps similar changes occur in the postural control system as children develop. It has been shown by Lee and Aronson (1974) and Butterworth and Hicks (1977) that children are highly dependent on visual cues when first learning to stand, but begin to loose this dependence with progressive maturation. It is well known that in the adult, both somatosensory and vestibular systems contribute to postural stability in addition to the visual system. In fact, of the three systems, the somatosensory system dominates (Nashner, 1976; Nashner and Berthoz, 1978). This developmental trend may reflect a decreasing dominance of visually elicited responses concomitant with increased response variability as the child learns to integrate the three sensory systems in balance control. It is of interest that the neuromuscular patterns contributing to postural control stabilize at 7-1/2 to 10 years of age, approximately at the time when the cerebral cortex is noted to complete its maturational process (Bronson, 1974)

Though postural control is a required foundation for most motor skills, a child must also be able to adapt his postural responses to changing task conditions. Forssberg and Nashner (1982) originally tested the ability of young children to attenuate adaptively postural responses when changing task conditions made them inappropriate. They compared the ability of the above four age groups to attenuate postural responses within five trials after introducing task conditions which made them destabilizing. Normal adults have previously been shown to adapt postural responses to new task conditions well within five trials. They noted (see Figure 9) that none of the youngest three age groups were able to adapt responses within five trials. However, children at 7.5 to 10 years of age showed adult-like behavior in adapting quickly. They concluded that children under 7 years of age were unable to successfully suppress inappropriate postural responses when necessary.



Average (±SD) adaptation ratios for each age group computed during sequences of five "toes up" and "toes down" support surface rotations. *Insets at right* show representative sequences of five consecutive gastrocnemius responses to "toer up" rotations.

Figure 9

These experiments have been repeated recently (Shumway-Cook and Woollacott, 1983) with longer trial sequences in order to determine if children actually were incapable of response modification or simply were slow to adjust. It was found that four of the six children of three to five years of age which were tested were capable of adaptively attenuating postural adjustments with sequences of 10 to 15 trials. This implies that nervous system mechanisms responsible for integrating information for the visual, vestibular, and somatosensory systems, and attenuating inappropriate responses, are functional, but not mature in this age group (see Figure 10).

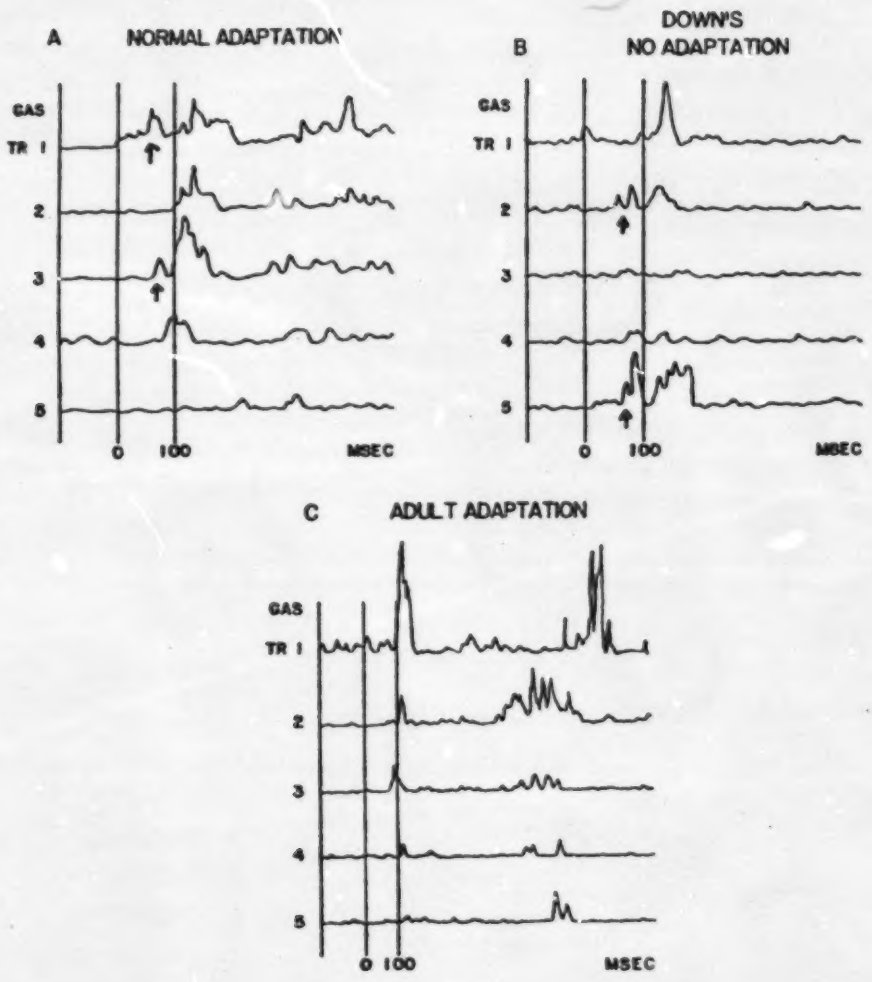


Figure 10

Adaptation of Postural Responses. Adaptive attentuation of inappropriate rotational responses in the normal adult and child, and lack of adaptation in Down's Syndrome children is shown. Lack of adaptation and presence of short latency myotatic responses, normally inhibited in standing adults, is suggestive of insufficient descending control over low level spinal mechanisms.

Applications to Teaching Motor Skills

Motor development and specifically motor skill development in children historically has been studied from three different perspectives: 1) a neurophysiological perspective, involving the analysis of changes in both nervous system structure and function which may be correlated with changing motor abilities, 2) a biomechanical perspective, involving the analysis of structural changes in body size, the relative dimensions of the subcomponents, and the manner in which these mechanical component changes contribute to motor ability development, and 3) a cognitive psychological perspective, involving the analysis of changes in the stages of information processing abilities during development, in order to determine the ways in which the acquisition of perceptual, attentional, and decision-making processes contribute to motor skill development. I will focus primarily on information concerning the development of neurophysiological substrates and the manner in which they may affect our concepts concerning motor skills in young children.

One of the clear principles which emerges from the review of the eye-hand coordination and the balance control literature is that there is initially in all children a heavy dependence on visually triggered responses. In both posture control and visually elicited reaching in young children, responses tend to be less variable and faster in the youngest age group tested. In visually guided reaching, this appears to be due to a lack of the use of visual feedback during movement. In balance control, it appears to be in part due to a heavy reliance on the visual system and an inability to use appropriately feedback information from other sensory modalities (vestibular and somatosensory) in controlling sway.

The existence of a clear transition phase is apparent in both tasks. In balance control children's responses become increasingly variable, and hit peak variability at about 5 to 6 years of age, after which they attain adult-like characteristics. In balance control we hypothesize that, in this period of increasing variability, the child is progressively expanding his reliance on sensory information to systems other than the visual system. In this process he must learn to integrate appropriately information from the three sensory systems before his responses attain adult form. This period of transition may manifest itself in seemingly awkward coordination under certain environmental conditions, yet it is clearly a mandatory stage in learning to integrate successfully information from all the senses and to adapt responses to changing task conditions.

Though the transition phase occurs somewhat later for eye-hand coordination (7 to 8 years of age), it appears to have similar behavioral effects in producing, under certain task conditions, the appearance of reduced coordination. Yet it also appears to be a clear "integration" period, in which the child learns to switch from visually guided to visually open-loop conditions depending on the most efficient strategy for the task involved.

This appears to be a time of sensory exploration for the child in which he continually takes in information from all sensory modalities in order to practice flexible alterations between different modalities and open versus closed-loop guidance strategies. It appears that motor skill training at this age level should stress playfulness and exposure to a wide range of conditions. If a child is put under great pressure to perform to a criterion it is possible that he could revert to the more primitive but more accurate open-loop and visually dominated behaviors, and thus never progress beyond a rigid stereotyped form of motor skill. This could also be true of situations in which a child is limited to one form of closed-skill activity. This could possibly restrict his chances to encounter sufficiently varied conditions to accommodate optimally to changing conditions.

Our knowledge that children are predominantly visually dominated in balance control at early ages and unable to successfully shift to the use of other sensory modalities when incorrect visual inputs occur, should be used in guiding our expectations of children's motor learning capabilities under the age of 4 to 5. These observations and suggestions are consistent with those presented by Bressan and Woollacott (1982) in reformulating Jewett's model for a prescriptive paradigm for sequencing instruction in physical education. In this formulation, the first construction subphase in motor skill acquisition consists initially of a playful level of learning where the performer attempts to sort out the kinds of sensory information gathered from the visual, vestibular and somatosensory systems which are relevant to the skill or task to be learned.

I would hope that physical educator would continue to emphasize this early subphase of skill acquisition in the child's early years of development (possibly through age 7), rather than moving on to emphasize the skill subphase of stabilization. This would ensure that the child had adequate practice in a wide range of sensory circumstances to gain the appropriate integrational and strategic agility to move on to the final learning subphase of differentiation where he learns to vary, improvise and even compose new subroutines for action.

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